Special Technical Report 32

IONOSPHERIC AND MAGNETIC OBSERVATION AT BANGKOK, THAILAND DURING THE ANNULAR SOLAR ECLIPSE ON NOVEMBER 23, 1965

By: JAN E. VAN DER LAAN

Prepared for:

U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY 07703

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ORDER NO. 5384-PM-63-91

STANFORD RESEARCH INSTITUTE

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ABSTRACT

Vertical-incidence ionospheric measurements and magnetograms, made during the annular solar eclipse of November 23, 1965, are presented and discussed. A marked change in the F2-layer virtual height and considerable stratification of the F layer were observed, including formation of an F1.5 layer. The magnetograms indicate a large (approximately 25 percent) diminution relative to the normal solar daily variation. A maximum of 86 percent obscuration of the solar disk was observed at about 1009 hours local time (0309 GMT) at Bangkok, which was approximately 290 km from the center of the eclipse path.

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ACKNOWLEDGMENT

The author is pleased to acknowledge the contributions of Dr. Rawi Bhavilai, Member of Physics Department, Faculty of Science at Chulalongkorn University. Dr. Rawi provided the data for Fig. 2, Table II, and the photograph reproduced as Fig. 3, as well as participating in several stimulating discussions.

I INTRODUCTION

During the annular eclipse of the sun on November 23, 1965, ionospheric observations were made utilizing the equipment available at the Military Research and Development Center Electronics Laboratory (MRDC-EL) facilities in Bangkok, Thailand. Ionogram data (virtual height vs. frequency) were obtained from the C-2 ionosonde and a Granger ionospheric sounder system operating at Bangkok during the eclipse period.[1,2*] Another Granger sounder was used in the fixed-tuned mode to measure the amplitude of the vertically-incident echo from the F2 layer. Magnetometer data, taken at the MRDC-EL, were also available for evaluation.

The annular eclipse path of maximum obscuration crossed northeast Thailand (Fig. 1) approximately 290 kilometers from Bangkok. The observation at Bangkok was made during the morning hours (0804-1150), where a maximum of 86 percent solar-disk obscuration occurred.[†] Figure 2 shows a plot of disc obscuration vs. time that is based on visual observations. Figure 3 shows the sun as it appeared at five-minute intervals during the eclipse. Geophysical conditions on the eclipse day were exceptionally quiet, as shown in Table I (see Appendix).[3] It should be noted that visual observations made at the Bangkok Planetarium indicate an absence of any solar activity on the unobscured solar disk. This should present an excellent opportunity for researchers to observe eclipse effects during a quiet-sun period.

Ionospheric and magnetic measurements made during the solar eclipse can yield much information pertaining to the development of the ionospheric layers. Under total eclipse conditions, the earth, in the

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[*] References are listed at the end of the report.

[†] Visual observation data presented were made available by Professor Rawi Bhavilai, Director of the Bangkok Planetarium.

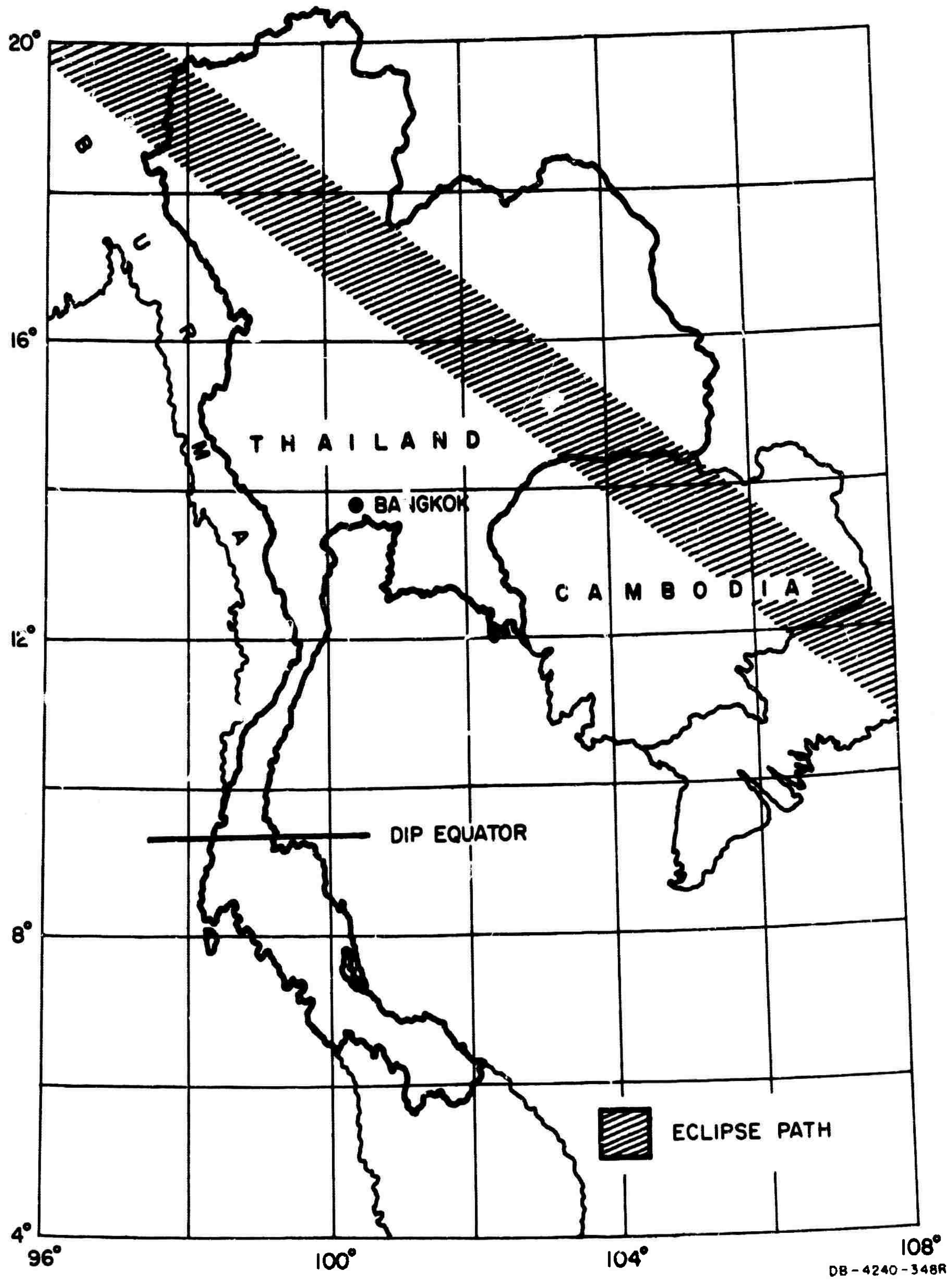

FIG. 1 MAP SHOWING ECLIPSE PATH

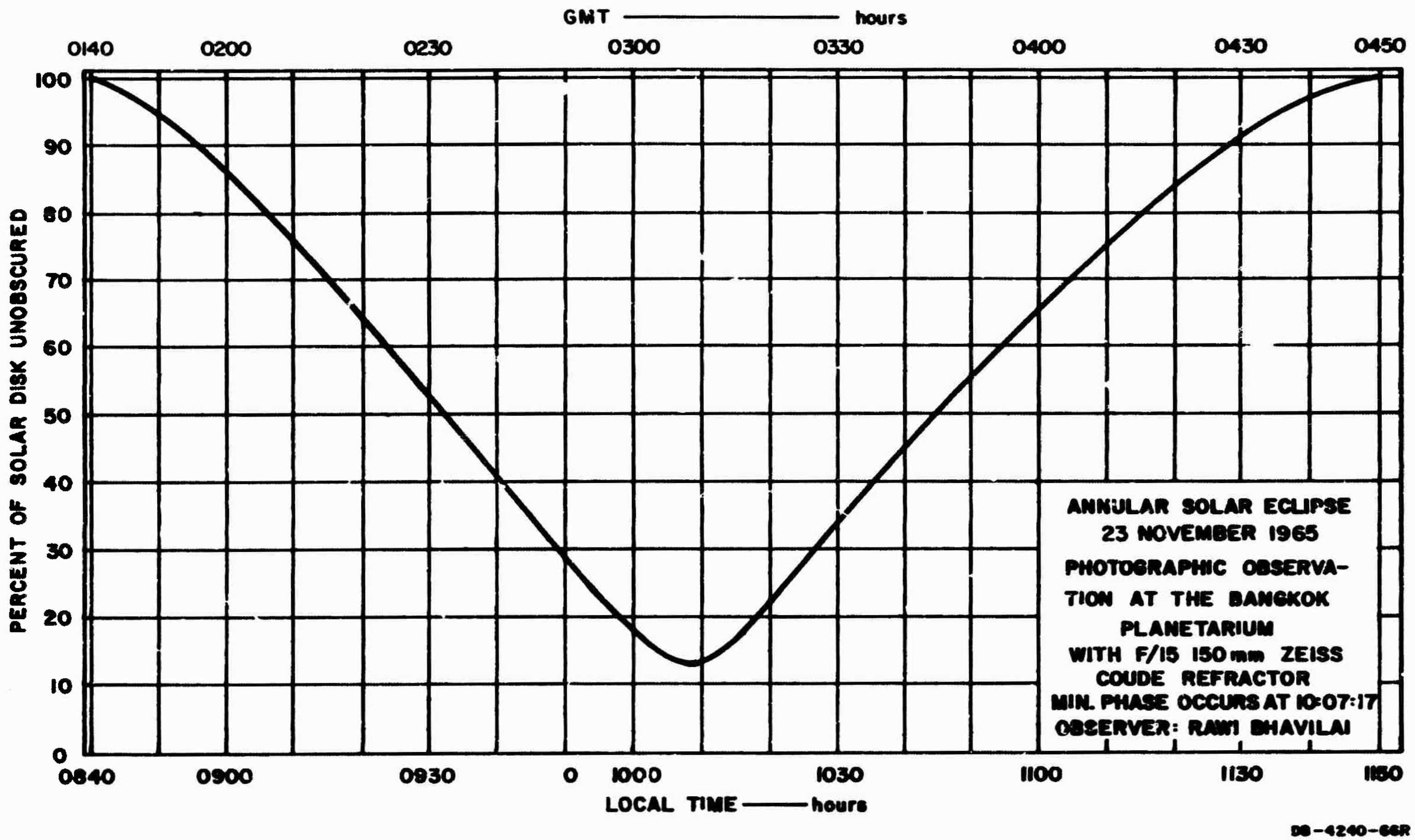

FIG. 2 PERCENTAGE OF SOLAR DISK UNOBSCURED FROM VISUAL OBSERVATIONS

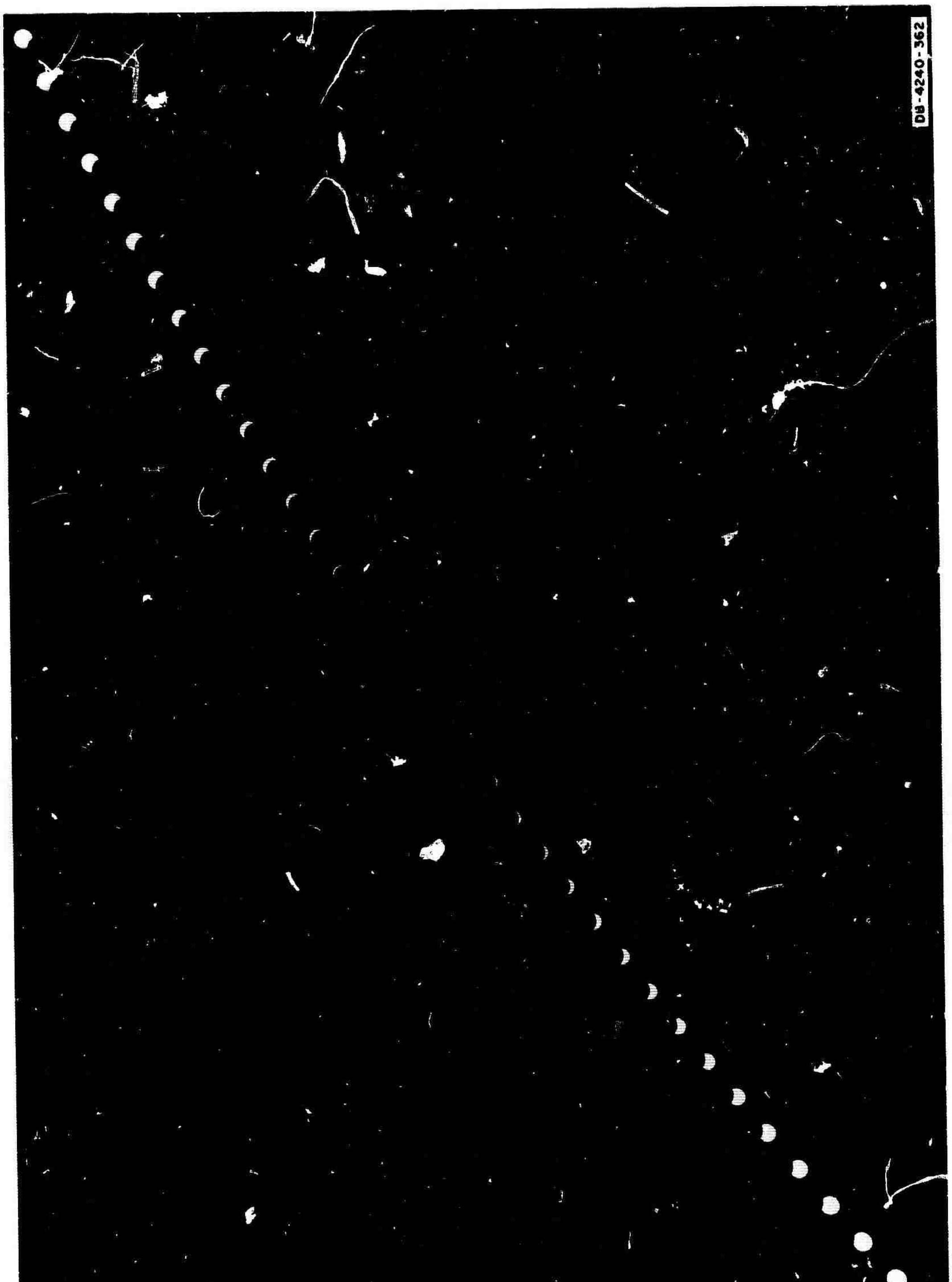

FIG. 3 MULTIPLE EXPOSURE OF SUN DURING ECLIPSE

path of totality, would experience a complete diurnal variation in solar radiation in a matter of a few hours (disregarding extrasolar radiation from beyond the visible solar disk). From such measurements, there is little doubt that solar photon emission is the main ionizing agent for the lower ionospheric layers (D, E, F1).[4] For these layers, reasonable agreement is found between theory and observation. The discrepancies that often exist are largely explained in terms of "active areas of ionizing radiation" (sunspot, flares etc.). While theory and results are in fair agreement for the lower layers of the ionosphere, there is still much uncertainty regarding the F2 layer. Because the normal behavior of the F2 layer is so irregular, eclipse observations vary largely. Reports range from those stating no observed effects to those stating gross changes in virtual height and formations of new stratifications.[5] Clearly, more studies of the F2 layer during eclipse phenomena and extensions to the measurement techniques are needed.

This report discusses the various measurements made at Bangkok and compares the results with other eclipse observations. Only a rudimentary attempt is made to explain the observed results.

II EQUIPMENT AND PROGRAM

A C-2 ionosonde is used at the MRDC Electronics Laboratory on a regular sounding schedule. During a control period five days before and five days after the annular eclipse on November 23, 1965, a fifteen-minute repetitive sounding program was used. On the day of the eclipse, a five-minute schedule was programmed. The system was used in the normal sweep-frequency mode, transmitting and receiving on a delta antenna system. The normal frequency coverage is from 1 to 25 MHz with peak power of approximately 10 kW in a pulse of 50 μs duration. The data above 3 MHz are quite good, but the local noise environment during the period of interest limited their use below this frequency.

Two Granger oblique ionospheric sounder systems were available at the MRDC-EL facility during the eclipse. These transceiver systems are capable of synchronization for oblique ionospheric studies. Their normal frequency coverage is from 4 to 64 MHz, step-tuned in 160 frequency steps. A peak power of approximately 30 kW is obtainable. Since broadband antennas were not available, it was not possible to use the systems to their full capacity. One system was used in the step-frequency mode with a reduced frequency spectrum of 4 to 8 MHz. Since effects on the F2 layer are of principal interest, this frequency range is fairly adequate at vertical incidence. In order to suppress interference without loss in sensitivity, we used a narrow receiver bandpass but transmitted a 500-μs pulse width. The poor mode definition due to the wide Granger pulse width was compensated by the C-2 data that were available. A dipole antenna, cut to resonate at 6 MHz, was used with this 4 to 8-MHz system; its narrow-band characteristics are evident in the data, but the data were still of great use in the overall evaluation. A five-minute program rate was used during the period of interest on the eclipse day.

Special measurements were made with the other Granger sounder, working in the monostatic mode (fixed-tuned), to sample the relative strength variations of signal reflected from the F2 layer at 7.05 MHz.

A one-minute sample was taken at five-minute intervals throughout the eclipse period. One millisecond (1 ms) pulses were transmitted and received at vertical incidence. A PRF of 20 Hz was employed in order to observe short-term fading. These amplitude data were recorded as a function of time on the Granger system 9190 electrostatic recorder, modified for amplitude recording.[6] A range-gate scheme was used to discriminate against unwanted mode (Es, multipath, off-path, etc.). For this measurement, the transmitted power was held constant (approximately 30-kW peak); therefore, the received pulse amplitude was a function of the propagation loss to and from the F2 layer. However, since accurate power measurements were not made, the received amplitude can be considered only a relative value. Impedance mismatch between antenna and receiver was not measured, but reasonable confidence can be placed on the receiver calibration.

Magnetometer data are taken on a continuous schedule at the MRDC-EL, measuring the earth's total magnetic-field intensity. A Varian Associates rubidium-vapor magnetometer, having both analog recording and digital printout.[7] is used. The analog recording is continuous. The digital printout, a direct reading in gammas, is made every two minutes.

III OBSERVATIONS

A. General Discussion of Data

In reducing the vertical-incidence sounding data, it was necessary to combine the results of the C-2 and Granger sounders in order to obtain more meaningful results. In general, the C-2 data were used primarily in determining the critical frequencies and observing the mode structure, while the Granger data were more useful in measuring the virtual height of the F2 layer (h′F2). The selected ionogram sequence shown in Fig. 4, covers the period of interest and shows the significant changes in ionospheric conditions. For simplicity, only the ordinary component is shown. The two plots, h′F and foF--shown in Figs. 5a and 5b, illustrate the data from the ionograms in more convenient form. The dotted lines in each of these plots represent the median values scaled for a control period five days before and after the eclipse day. The solid lines are the values scaled on the day of the eclipse. The h′F2 values on the eclipse day were not scaled prior to 0802 because an L condition* did not allow accurate scaling of this parameter.[8] Figure 6 presents the amplitude data taken at 7.05 MHz as a function of time. The solid line represents the eclipse-day measured values, while the dotted line shows the calculated values for a quiet solar day. The calculation is based on the solar control of ionospheric nondeviative absorption, A, using $A = C \cos 3/2\ \chi$, where C depends on frequency, season, state of geomagnetic activity, etc.,[9] and χ is the solar zenith angle. In my calculations, measured values recorded during another test at Bangkok were used to determine C, (C = 31.2).+

The magnetogram, shown in Fig. 7, is a plot of the average Sq variation (for a twenty-four hour period) of total magnetic field intensity in gammas. The selected control plot shown is the mean field

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*Qualified letter L is used in ionogram reduction when a sufficiently definite cusp between layers is not present. Critical frequency and virtual heights cannot be determined under this condition.

+Data obtained from unpublished technical memorandum.

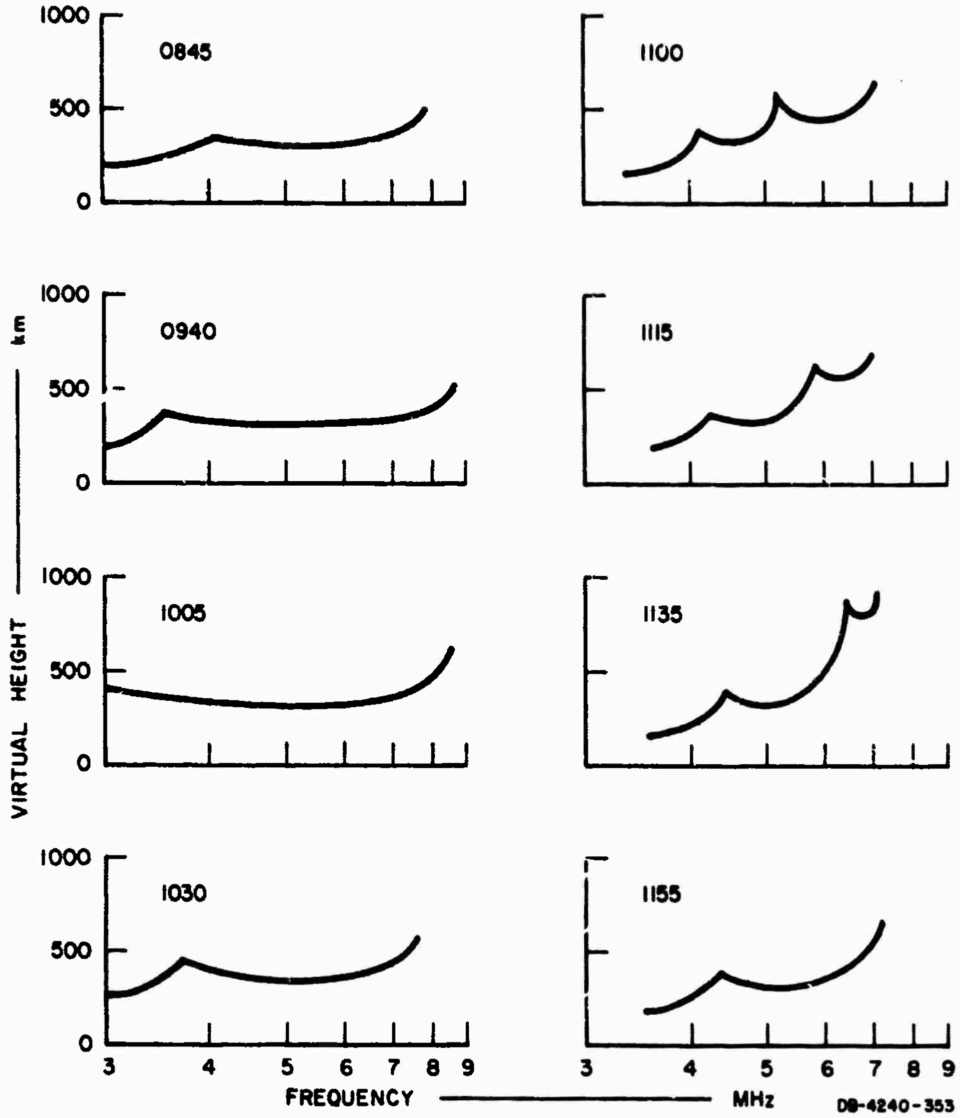

FIG. 4 IONOGRAMS SHOWING MAJOR CHANGES DURING ECLIPSE

intensity on several geomagnetically quiet days of the same lunar and seasonal cycle as the eclipse day.* The mean geomagnetic Sq variation is also shown for the days before and after the eclipse day.

On all data plots, the annular eclipse phase is shown. By definition the first contact is the time when the moon first starts to obscure the visible solar disk, as observed from the monitoring station. The

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*Data obtained from unpublished geomagnetic measurements at Bangkok.

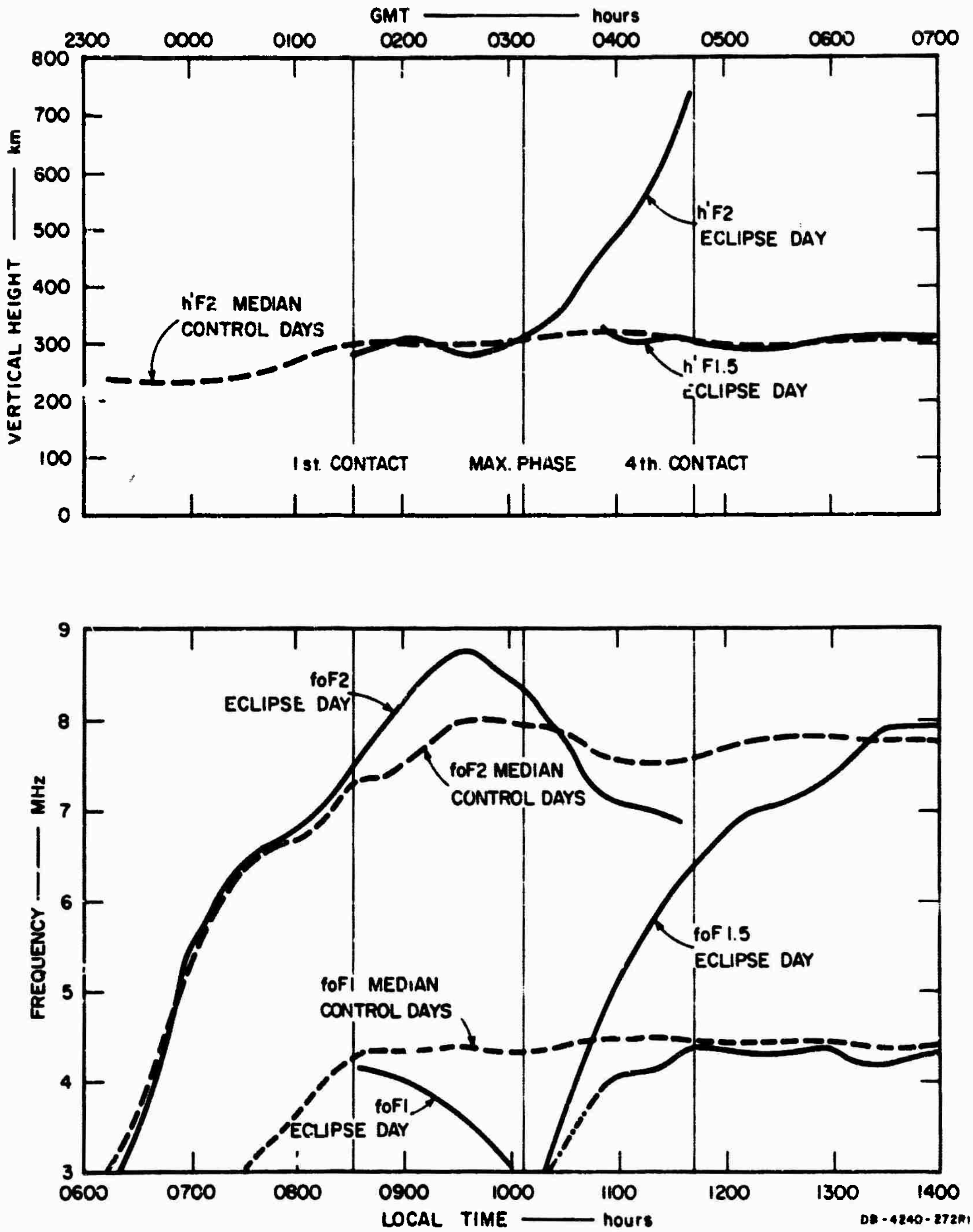

FIG. 5 VARIATION OF IONOSPHERIC PARAMETERS DURING ECLIPSE

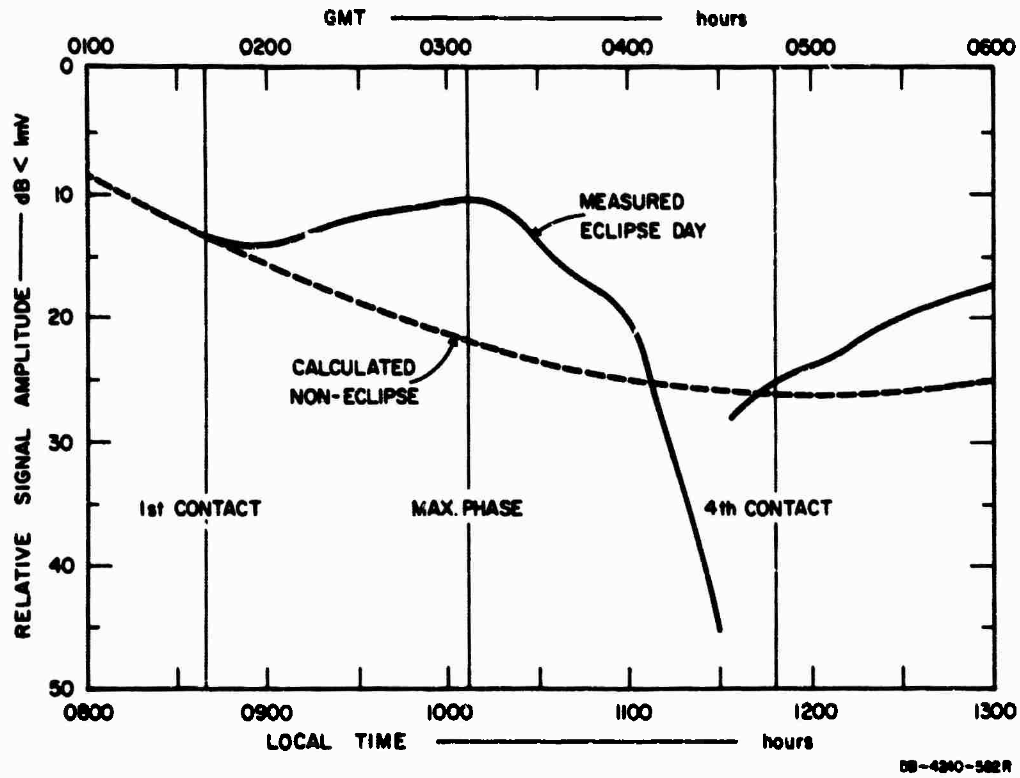

FIG. 6 7.05-MHz RELATIVE SIGNAL AMPLITUDE vs TIME

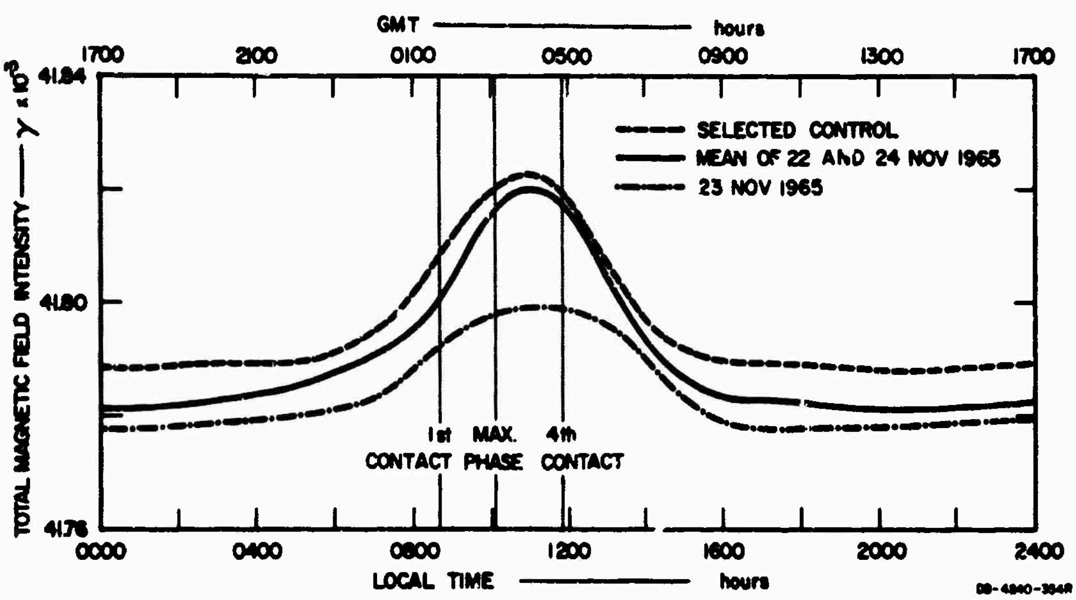

FIG. 7 VARIATION OF TOTAL MAGNETIC FIELD DURING ECLIPSE

first phase will be known throughout this report as the period following first contact and up to the maximum obscuration (increasing solar-disk obscuration). The maximum phase is the period of maximum obscuration, which lasts approximately 4 minutes. There are no second and third contacts when the eclipse is either partial or annular. The second phase is that period following the maximum phase until fourth contact (decreasing solar-disk obscuration). Fourth contact is that time when the moon no longer masks any part of the visible solar disk. All plots are made in reference to both local time and GMT.

B. Summary

The observations of ionospheric and magnetic effects may be summarized as follows:

F1 layer: The response seems to follow the "simple" layer analysis of decreasing ionization with increasing solar obscuration. With the data available, recombination (α) rates cannot be estimated.

F1.5 Layer: During the second phase, a new stratification (F1.5) is present between F1 and F2. Its critical frequency increases until it replaces the F2 layer on the ionograms. The F1.5, which is not uncommon in equatorial areas,[10] was not present during any of the control days.

F2 Layer: During the first phase of the eclipse, no effects were noted in the F2 layer. Following the maximum phase, the virtual height of the layer increased at a rate of approximately 5 km per minute, reaching a peak of approximately 750 km. During this period, the F1.5 critical frequency was increasing, thereby decreasing the F2-layer frequency spectrum. This process continued until the critical frequencies merged and there was no longer the old (F2) stratification. Throughout this second phase, the ionogram records showed a significant difference between the minimum vertical height of the F1.5 and the F2 layers, indicating an extremely thick F1.5 layer.

7.05-MHz Relative Signal Strength: Throughout the first phase and most of the second, the relative signal amplitude seemed

to follow in phase with the percentage of obscuration of the solar disk. This is probably due to D-layer absorption (nondeviative), which is directly solar controlled. Non-deviative absorption effects are relatively small at 7 MHz, where the angular wave frequency (ω) is much greater than the collision frequency (ν) of constituents of the D region. One hour after the maximum phase, as the F1.5 critical frequency approached 7.05 MHz (extreme cusping existing), the deviative absorption began to increase at a very rapid rate of approximately 1 dB per minute. This continued until the stratification apparently disappeared. Shortly after last contact, the 7.05-MHz frequency was supported by the F1.5 or "new F2" layer and was recovering to the normal relative signal strength.

Magnetometer Data: The maximum phase of the eclipse occurred during a period when the diurnal variation of the earth's total field intensity was nearing its maximum change. The results show a diminution of approximately 25 percent on eclipse day, relative to the mean Sq variation of other days.

C. Observation Analysis

1. F1 Layer

From the critical-frequency data shown in Fig. 5b, it can be seen that there was a well developed F1 layer by 0830 (local time) on the control days. The foF1 value had reached 4.45 MHz by this time and remained at this value (± .1 MHz) throughout the period of interest. Prior to first contact on the eclipse day (0840), the foF1 had reached approximately the value of the control days. Insufficient cusping of the F2 layer did not allow scaling before 0830 (L condition). By 0900 it was apparent that the increasing solar obscuration was having marked effects on the F1-layer ionization. At 1006 (maximum phase) the foF1 was below the usable frequency spectrum of our data (3 MHz). After the maximum phase, the foF1 increased rapidly so that at fourth contact (1150) the foF1 was again approaching the mean value of the control days. During the second phase of the eclipse, the appearance of

stratification between the F1 and F2 layers (F1.5) and another L condition prevented accurate scaling of the foF1. Since it was not possible to scale virtual height on the F1 layer (due to lower frequency limitation), the data are of little use in determining loss processes. From the F1 observation, one can only surmise that the layer ionization was directly proportional to the percent of solar radiation unobscured; a Chapman-like process seemed to occur.[10]

2. F2 Layer

The normal variations of daily foF2 plots are so large that it is difficult to determine a meaningful average value. A control-day value is often derived using the median of a five-day period before and a five-day period after the eclipse day.[11] But this can be misleading,* and caution should be used in evaluation of foF2 characteristics. An exception to this generalization of the foF2 plot is the early morning ionization process. Between 0615 and 0830, deviations in the increasing foF2 value over the entire control period were extremely small. On the eclipse day, the morning ionization process seems to have been quite normal until 1000 when the foF2 started to decrease at an abnormal rate. (Although the peak foF2 on the eclipse day was greater, for the period 0830-1000, than the control day median value, the difference of about 0.5 MHz is probably insignificant considering the variable nature of the F2 layer). The decrease in foF2 at approximately 1000 does appear to be abnormal since it also correlates with a change in the h′F2. Figure 5a indicates that the h′F2 values on the eclipse day were normal with respect to the control median until approximately 1000 when the h′F2 started to increase at a very rapid rate. Referring to Fig. 5b, note that at approximately 1015 a stratification between the F1 and F2 started to appear. It was hard to distinguish the F1.5 from a normal F1 at that time since the F1 was below the usable frequency limits (3 MHz) and not present on the data. As time progressed, however, the presence of the new stratification became obvious. By 1130, the foF1.5 was approaching the foF2, and they seemed to merge. By definition, the

*Using quartile or decile bounds about the median helps ward off misleads.

new stratification became the F2 layer (F2 is defined as the highest stable stratification[8]) at that time. The layer, new F2, continued to increase in critical frequency until 1315 when it seemed to level off at approximately the median value of the control period. (The ionogram sequence, shown in Fig. 4, covers the period of maximum change in the F2 region characteristics and is helpful in evaluation of the changes which occurred.)

3. 7.05-MHz Relative Signal Amplitude

It is regrettable that a control period observation of the signal amplitude on 7.05 MHz was not made. It is believed, however, that the normal variation in the relative signal amplitude should be a function of lower-layer absorption (nondeviative) and should follow its diurnal variations in the case where the measured frequency is well below the layer's critical frequency. In this case, since all of the control-day F plots show that foF2 was well above 7.05 MHz, we can expect the variation in signal amplitude to be approximately that which is shown as a dashed line in Fig. 6. Assuming this to be correct, let us examine the variations during the eclipse. The slight rise in amplitude during the first phase may have been due to a decreasing absorption level as the solar-disk obscuration was increasing. Using this reasoning, we might expect the opposite following the maximum phase, as the absorption was increasing. This seems to have been the case for a part of the period (1000-1100) following the maximum phase, although the changing amplitude rate was somewhat greater than before. This increased rate of change may be reasonable since the solar zenith angle (χ) was decreasing (see Appendix, Table II), and that could account for an increase in nondeviative absorption. However, at approximately 1110, the signal amplitude started to decrease rapidly at approximately 1 dB per minute until 1140. This period is important, and we should look at the ionogram sequence (Fig. 4) to get a better feel for conditions.

A first look at the ionogram at 1115 shows that our sample frequency at 7.05 MHz is right at the foF2, and we might assume that the increased loss in signal strength was due to deviative absorption during

reflection in the F2 layer.[12*] This assumption may be misleading, however, for the extraordinary component could have been supporting our sample frequency while the ordinary component was being deviatively absorbed. A check of the foF2 traces on the ionograms, from which Fig. 4 was drawn, shows that this was the case. Separated in time at this point, the two components (0 & χ) exhibit individual amplitude characteristics, and the χ component also shows a marked decrease in signal strength. Indeed, the entire stratification, F2, is showing marked amplitude reduction. The C-2 data, which are not generally an indication of signal strength, were becoming very weak for the F2 mode and were not present at all after 1115. The greater system sensitivity of the Granger allowed scaling after that time. What then was causing this rapid decrease in signal strength?[†] Another look at the ionogram sequence (Fig. 4) shows that prior to 1030 there was very little change in the F2 mode structure. (The extension to the lower frequency limit is really a change in F1 characteristics.) At approximately 1030 a stratification, F1.5, started to appear below the F2, and its critical frequency increased until it was the same as that of F2. The large difference between the vertical height of the F1.5 and F2 layers indicates a very thick F1.5 layer, which may explain the abnormal absorption increase during hours of its formation. [It will be remembered from the discussion of h′F2 data (Fig. 5a) that this is the period during which the h′F2 value was also increasing at a very rapid rate, also indicating additional path loss.] At approximately 1140 (Fig. 6) the signal amplitude at 7.05 MHz fell below the system sensitivity for the (old) F2 mode. Since our sample rate was on a five-minute schedule, it

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*It is well known that at the junction frequencies of vertical-incidence modes, there is increased deviative absorption due to the relatively long time the exploring wave spends at this level where the real part of the refractive index is small.

†It would be of great assistance to reduce the data to an electron density profile, but the data is not of sufficient quality to do so with any accuracy. Lack of data below 3 MHz would necessitate utilizing an assumed profile for the E and F1 layers, and this would introduce too many uncertainties.

is difficult to say when the F1.5, new F2, layer began to support our sample frequency. But, at 1145 we adjusted our sampling gate in order to record the fxF1.5 signal amplitude. From the F plot data (Fig. 5b), we can see that the ordinary ray component foF1.5 did not reach our sample frequency until 1230. By 1300, our signals seemed to be following the normal daily variation although offset by approximately 7 dB, which was probably due to the mean absorption level, after the eclipse, being lower than that of a normal day.

4. Magnetometer Data

As in most eclipse observations, a comparison of magnetic perturbations on the eclipse day is made with those of preceding and succeeding days.[13] In addition, since the eclipse day was considered a magnetically quiet day, a control-day plot of several magnetically quiet days was drawn to represent a normal Sq variation. As shown in Fig. 7, the control-day variation is 35 gammas, while the variation of the median of the days prior to and following the eclipse day is 40 gammas. On the eclipse day, the Sq variation was 25 gammas. In reference to the normal Sq variation this is a 25 percent diminution, while it represents a 37 percent change from the mean of the day before and after the eclipse. This large change is due to the fact that the eclipse occurred slightly before the period of maximum normal daily variation. Such a change is to be expected if currents in the lower ionospheric layers are responsible for the daily magnetic-field intensity variation. (It has already been shown that the lower layers seemed to follow the simple layer process during the eclipse.) Observing the eclipse-day magnetogram, the first departure from a normal Sq variation seems to occur simultaneously with first contact. Approximately one hour after fourth contact, the plot seems to be following the normal Sq change again.

IV COMPARISON WITH OTHER ECLIPSE OBSERVATION RESULTS

In the introduction, it was mentioned that F2-region observations during solar eclipses vary grossly. This is largely true, but does not mean that there are not similarities. In a survey of past eclipse observations, J. A. Ratcliffe (1955) summarized the effects in tabular form.[5] Examination of these effects shows some very interesting similarities to our observations. The rapid increase in virtual height of the F2 layer following the maximum phase is noted at several locations. Also, at these same locations, there is almost always a presence of the F1.5 stratification during the eclipse. It is significant that at all locations where these effects were observed, the magnetic dip angle is less than 20°. In an observation at Gangui, Africa (Lejay and Durand, 1952)[15] where the magnetic dip angle is close to that of Bangkok, the observation was almost identical to that which we observed. Lejay and Durand state, "There is clear evidence for the appearance during the latter half of the eclipse of a new F2 stratification below the 'old F2' layer." Rapid increase in height of the 'old F2' layer, without change of its critical frequency, also seems to accompany the appearance of the 'new F2' layer." Lejay and Durands' report is particularly interesting for it presents a sequence of ionograms that correlate almost identically with Fig. 4.

It is rather difficult to compare magnetometer data with past observations since our measurement is of total field intensity, whereas most earlier measurements are of individual components. Nevertheless, our results are in fair agreement with many past observations. Chapman (1933) suggests that 28 percent reduction in the Sq variation of the horizontal component can be anticipated if currents in the E layer are responsible for the daily variation.[15] Although our measurements are of total field intensity, it should be pointed out that, due to our geomagnetic latitude (2.5°N Lat., dip angle $\approx 10^{\circ}$), the major portion of the field intensity is the horizontal component. Our measured departure of 25 percent from the normal Sq variation seems quite in order. In addition, since the 28 percent departure from the normal Sq variation suggested by Chapman is based on total eclipse conditions, we should

expect somewhat less of a change in our measurement. Egedal (1955) presented a weighted mean evaluation of many stations observing the eclipse of June 30, 1954, and a 29 percent departure was noted. This compares very favorably with Chapman's investigation.[16]

Appendix

Analysis of eclipse data requires a knowledge of geographic location of the observing station, these parameters follow:

Bangkok, Thailand

Geomagnetic Latitude . . . . . $2.5^{o}N$ Geographic Latitude . . . $13.73^{o}N$

Geomagnetic Longitude . . 16[illegible].$83^{o}E$ Geographic Longitude . . $100.57^{o}E$

Magnetic Dip Angle . . . . . . $10^{o}N$

Geophysical conditions affecting the ionosphere should also be known in order to better understand the changes taking place during an eclipse study. Table I presents some conditions known to have a direct effect on ionospheric conditions. A period five days before and after the November 23, 1965 annular eclipse are shown.

Table I

SOLAR AND MAGNETIC DATA

Geophysical Data	November 1965										
	18	19	20	21	22	23	24	25	26	27	28
Sunspot Number Zurich Daily Total	0	0	0	0	7	0	7	0	7	0	8
Solar Flares Daily Total	0	4	2	0	1	3	1	1	1	3	6
Magnetic Activity Indices Kp Total	12+	19+ D*	25+ D	18-	9_o	3- Q+	9-	9_o	8-	9_o	4_o Q

*Magnetically Disturbed Day

+Magnetically Quiet Day

Ionization-process calculations are dependent upon solar zenith angle (χ) as a function of local time. The following list gives the solar zenith angle for the period of interest on 23 November 1965.

Table II

SOLAR ZENITH ANGLE VS. LOCAL TIME AT BANGKOK, 23 NOVEMBER 1965

Bangkok Standard Time	GMT	Zenith Angle Degrees	Bangkok Standard Time	GMT	Zenith Angle Degrees
0804	0140	61.4	1020	0320	43.6
44		60.6	24		43.1
48		59.9	28		42.4
52		59.0	32		41.9
56		58.3	36		41.5
0900	0200	57.5	40		41.0
04		56.6	44		40.4
08		55.9	48		39.9
12		55.2	52		39.6
16		54.4	56		39.0
20		53.6	1100	0400	38.6
24		53.0	04		38.3
28		52.1	08		37.9
32		51.4	12		37.5
36		50.8	16		37.3
40		50.1	20		37.0
44		49.4	24		36.8
48		48.6	28		36.3
52		47.9	32		36.1
56		47.4	36		35.9
1000	0300	46.7	40		35.7
04		46.0	44		35.7
08		45.4	48		35.5
12		44.9	52		35.5
16		44.2	56		35.3
			1200	0500	35.3

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13. ABSTRACT

Vertical-incidence ionospheric measurements and magnetograms, made during the annular solar eclipse of November 23, 1965, are presented and discussed. A marked change in the F2-layer virtual height and considerable stratification of the F layer were observed, including formation of an F1.5 layer. The magnetograms indicate a large (approximately 25 percent) diminution relative to the normal solar disk was observed at about 1009 hours local time (0309 GMT) at Bangkok, which was approximately 290 km from the center of the eclipse path.

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